Overview

- Background
- Manned Spaceflight – NASA applications
  - Wing Leading Edge Impact Detection System
  - Distributed Impact Detection System
- Unmanned Spaceflight – Military applications
  - Hit Grids
  - Wireless Hit Grids
- Other Applications
  - Lightning strike detection & location
  - Next Generation Spacecraft HVI detection & location
Invocon, Inc.

- Founded in 1985
- Located in Conroe, Texas
- Veteran-owned Small Business
- Employs Electrical Engineers, Technicians, Computer Science and Administrative personnel

Invocon's core activities revolve around research and development of precision instrumentation and communication solutions for demanding applications in extreme environments.
Applications

Application Areas:
- Aircraft / Spacecraft Test and Eval.
- Mechanical Condition-Based Maint.
- Missile-Defense
- Civil Structural Monitoring

Invocon Flight Systems:
- Structural Analysis ISS
- 40+ Shuttle flights, including 17 unique systems
- 5 systems aboard the ISS
- 20+ Flights – Instrumentation on Navy/MDA Target Missiles
Rationale for Event-Triggered Inspection

- Inspections can be too costly or even impossible

Challenges based on:
- Vehicle configuration – can’t get there to inspect it
- Vehicle environment – unsafe to inspect
- Mission objectives – will interfere with mission
- Mission timeline – don’t have time
- Mission Cost – fuel, personnel, volume, mass, $$

Considerations:
- Must minimize triggering instrumentation or risk mission objectives – SWaP-C
- Triggered events may require re-evaluation of mission

However: If it isn’t broken, don’t meddle with it!
Wing Leading Edge Impact Detection System

- Shuttle return to flight
- In-flight inspection = primary safety assurance
- Impact Detection System = important to identify damage
  - Notify of occurrence
  - Pinpoint location
  - Simplified inspections
- Used for
  - Launch to Orbit
  - MMOD while orbiting

Hardware:
44 sensor units, 22 per wing, mounted in 2 locations
Each unit has 3 accelerometer channels & 1 thermal sensor
132 accelerometers mounted inside wing spare panel
Wing Leading Edge Impact Detection System

Sensor Units record and post-process accelerometer and temperature readings during ascent and while on-orbit.

Relay Units collect (via RF) post-processed data from Sensor Units and transfer to crew compartment via wired RS-485 multidrop networked bus.

Laptop-based Receiver Assembly collects (via radio frequency) data from Relay Unit and dumps data to PC for downlink to Mission Control.

Monitored impacts on Shuttle wing leading edge during ascent and Micro-Meteor and Orbital Debris (MMOD) impacts in orbit.

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WLEIDS Hardware Overview

### Enhanced Wide Band Micro Tri-axial Accelerometer Unit (EWBMTAU)

- 3 Accelerometer or Acoustic Pressure Channels
- 1 Temperature Channel
- USB 1.1 Port
- Bolted Attachment includes lid
- Removable Lids for Battery Replacement
- Patch Antennas for RF Relay
- 12oz = 340gm
  - 3.25” x 2.75” x 1.5”

#### Details:

- **Accelerometer:** Piezoelectric Charge Output
  - Endevco 2221F / 0.39 oz = 11 gm / .966” x .6” x .52”
  - 10 pC/g sensitivity
  - Bolted to a nut-plate with fastener/washer
  - Sinusoidal vibration limit: 100 g pk
  - Shock limit: 3000 g pk

### Cabin Relay Unit (CRU)

- Relay Unit 485 Connectivity to Crew Cabin (wired)
- 8oz = 227gm
  - 2.69” x 2.23” x 1.14”

- 3 Accelerometer or Acoustic Pressure Channels
- 8oz = 227gm
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WLEIDS Accelerometer Installation

Accelerometers installed behind WLE spar near the upper/lower attach bolts for RCC Panel assemblies.

Photographs looking forward inside port wing.
Sensor Configuration for Ascent Monitoring
Cross-strapping for Quadruple Redundancy

Port (OV-103)

Starboard (OV-103)
Implementation Details

First Flight – Trigger levels
- Optimal levels unknown
- Set very low to insure that all meaningful events were captured
  - Flood of data – levels increased for subsequent flights
  - Compared data with in-flight and ground inspections

Expanded operations
- Micro-Meteoroid and Orbital Debris (MMOD) Mode
  - Probability of impact with MMOD is increasing significantly
- Used to monitor vehicle during orbit
- Reduce Redundancy – increase time
Simplify by Automated Processing

- Too much data to download in flight!
  - 256 MBytes x 44 units
  - 11 Gigabytes
- Must process data onboard each sensor unit
- What to Download?
  - List of impact events prioritized by level
  - Processed data
  - Some raw data if required
  - All data after landing

Raw Flight Data

Processed Data showing Impact Events
Distributed Impact Detection System (DIDS)

- Provides ultra low power impact detection circuitry designs for continuous monitoring of structure for accelerations or high rate strains caused by impacts throughout all mission stages
  - Sample rate: ~900 kHz
  - 4 channels / device
  - Low-power trigger modes
  - A/E, Acceleration, Ultrasonic

- Wireless communication decreases implementation cost

- Present ISS applications:
  - Leak location
  - Impact detection on BEAM
Launch Vehicle Instrumentation

The following systems are designed to increase the capabilities of launch vehicles while decreasing cost.

Some cost reduction is through simplified integration

Some of these devices include wireless interfaces. All of these devices are designed to be used with wireless telemetry.

These systems are examples of instrumentation for systems that cannot be inspected due to the nature of their missions.
Hit Detection/Location Systems

- Telemetry Data Acquisition System - TDAS
  - Measures the response of a grid of up to 256 coaxial wires – 160 ns sampling
  - Telemeters data to Ground Receiving Units (GRUs) at 10Mbps
  - Self contained (power and communication)

- Kinetic Impact Position System – KIPS
  - Low cost version of TDAS
  - Integrates with vehicle power and communication
  - 80 ns sampling
  - Intelligent com link sharing to insure all important data is transmitted

- Have provided impact location for 20+ vehicles
Grid-less Hit Grid (Patented)

- Grid-less transduction technology replaces or augments wired hit grid
  - Acoustic and/or RF sensing
- Simplifies integration
- Installs on vehicle skin
- Reduces weight
- Provides enhanced situational awareness
- Enables detection of multi-impact events (i.e., Shrapnel kill weapon)
Hypervelocity Impact Damage Assessment System

- Phase I SBIR
- Expands from *detection* and *location* to *evaluation*
- Characterize HVI signals
- May have limited time after HVI event to evaluate damage
- Much work to be done!
Surface-borne Time of Arrival Measurements (STORM) (Patent Pending)

- Designed to detect, locate, and evaluate lightning strikes on aircraft
  - Immediate feedback to flight crew
  - Detailed feedback to maintenance personnel
- Sensing is similar to HVI technology
- Developed technology to simplify installation and operation
  - Key objective of recent work
New Wireless HVI Detection and Location
(Patent Pending)

- Distributed wireless sensor network
- Based on heritage impact location and new wireless synchronization capabilities
  - Wireless distributed synchronization to better than 1 nano-second!
  - Simple hardware and low bandwidth minimizes cost ($ and resources)
  - Simplifies installation and operation.
- Applicable to wide range of instrumentation
  - Can increase efficiency of RF Communication
Summary

- Event-triggered inspections are used by NASA in critical applications
- Impact detection and location are particularly useful in aerospace applications where structural mass is minimized
  - Lower safety margin than other applications
  - Impacts are a real possibility
- Cost-effective (Time and $$$)
- Minimizes exposure of structure to potential for additional damage
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